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SOME TEMPERATURE CHARACTERISTICS OF STREAM AND INTRA-GRAVEL WATER IN CARNATION CREEK, BRITISH COLUMBIA

by

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ABSTRACT

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Twenty series of measurements of stream and intra-gravel water temperatures were made in Carnation Creek above the zone of tidal influence during a one year period. Four series were made in the part of the stream that was within the zone of tidal influence. Intra-gravel temperatures within a series were more variable than those of the stream and tended to be lower than those of the stream in summer and higher, in winter. In several of the series of measurements taken during the summer stream temperatures were relatively low in the areas where the intra-gravel temperatures were low. In such temperature series taken in summer stream temperatures were progressively lower from upstream, at such sites, to downstream. During series of measurements taken in winter and early spring the stream appeared to warm along the length within the reach where temperatures were taken. In the zone of tidal influence summer intra-gravel temperatures, apparently influenced by warm incoming tide water, were higher than those of the stream.

The paper discusses the fact that measurements of stream temperatures at specific sites may not indicate very well what the intra-gravel temperatures, at egg incubation depth, may be. Where artificial egg introductions are made and there is a desire to know or control the time of emergence this should be kept in mind. Secondly, the paper discusses the fact that during summer, in a clear-cut area of the stream, water temperatures become progressively lower downstream. The fact that this may occur in some situations should be recognized by fisheries people, evaluating forest harvest impacts.

Key words: Stream temperature, inter-gravel temperature, salmon egg incubation, stream ecology.

RÉSUMÉ

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Pendant un an, on a effectué dans le ruisseau Carnation, au-dessus de la zone d'influence des marées, 20 séries de mesures de la température de l'eau du cours d'eau et à l'intérieur du gravier. Quatre séries ont été faites dans la partie du cours d'eau qui se trouvait à l'intérieur de la zone d'influence des marées. Les températures enregistrées à l'intérieur du gravier dans une série étaient plus variables que celles du cours d'eau et elles tendaient à être plus faibles que celles du cours d'eau en été et plus élevées en hiver. Dans plusieurs des séries de mesures prises pendant l'été, les températures du cours d'eau ont été relativement basses dans les secteurs où les températures de l'eau à l'intérieur du gravier étaient faibles. Dans ces séries de températures prises en été, les températures du cours d'eau ont été progressivement plus faibles de l'amont, à de tels emplacements, vers l'aval. Au cours des séries de mesures prises en hiver et au début du printemps, le cours d'eau a semblé se réchauffer le long du secteur où les températures ont été prises. Dans la zone d'influence des marées, les températures enregistrées à l'intérieur du gravier au cours de l'été, apparemment influencées par l'arrivée d'eau de mer chaude, ont été plus élevées que celles du cours d'eau.

L'article fait valoir que les températures relevées à des endroits précis pourraient ne pas indiquer très bien ce que peuvent être les températures à l'intérieur du gravier, à la profondeur d'incubation des oeufs. On doit en tenir compte lorsque l'on procède à des introductions artificielles d'oeufs ou lorsqu'on désire connaître ou contrôler le moment de l'éclosion. Deuxièmement, on discute le fait qu'en été, dans une zone déboisée du cours d'eau, les températures deviennent progressivement plus faibles vers l'aval. Le fait que cela puisse arriver dans certaines situations doit être reconnu par les gens des pêches, lorsqu'ils évaluent les répercussions de l'exploitation forestière.

Mots clés: température du cours d'eau, température à l'intérieur du gravier, incubation d'oeufs de saumon, écologie du cours d'eau.

INTRODUCTION

During 1981 and 1982 several series of intra-gravel water and stream temperatures were recorded along the length of the lower reaches of Carnation Creek, British Columbia. The measurements were made, year around, as a part of a study of coho salmon (Oncorhynchus kisutch) spawning distribution. The objective of this paper is to present the stream and intra-gravel temperature information because it may be of direct interest to managers involved in widely differing activities, e.g., habitat biologists evaluating clear-cut logging effects and workers planting fish eggs.

In the case of fisheries forestry investigations series of stream temperatures are, not uncommonly, taken to evaluate the effects of logging clear-cuts on stream temperature characteristics. The expectation in these cases is that the water may warm as it passes through cleared areas. However, local influence of ground water may offset such warming effects. The possibility of such an influence should be recognized.

Workers involved in salmonid enhancement activities may plant eggs in a stream substrate in the assumption that the temperature conditions in the gravel are the same as those in the stream or that intra-gravel water temperatures are uniform along a stream. In Carnation Creek neither of these assumptions are justified.

Stream velocity characteristics, temperature in above-bottom parts of the stream and substrate type are often considered as conditions that may determine local differences in invertebrate fauna composition or production rate. In the zone of stream influenced by tides, substrate type, water temperature above the bottom, water velocity and nutrient loading are recognized as features that may affect invertebrate production. This paper presents some preliminary information on stream and estuary intra-gravel (stream-bed) temperature conditions and poses questions about the role of such conditions in invertebrate production.

STUDY AREA

Carnation Creek, draining a 10 km^2 catchment basin, runs into Barkley Sound on the west coast of Vancouver Island, British Columbia (Fig. 1). The stream runs to sea from an elevation, at its highest point, of about 880 m. Precipitation in the area ranges annually from 210 to 400 cm per year. Most of it falls as rain in the winter months. The stream discharge ranges from a low of 0.03 m^3/s to a high of 44.3 m^3/s in the summer and winter respectively (Hetherington 1982). The predominant rock in the basin is dense, medium to dark gray in color, and generally porphyritic. There are several faults or shear zones of larger magnitude in the basin (Eastwood 1975). The slope soils, over the bed-rock, are shallow with an average depth of about 70 cm. They are composed of coarse colluvial materials of gravelly loam to loamy sand with an organic layer over them (Oswald 1973).

From the estuary to about 500 m, upstream the valley bottom is flat. It is constricted from about the 500 m to 700 m point. From about 700 m to 3000 m the bottom land areas are generally flat until they reach the valley walls. The stream channel from the estuary to the 3000 m point has a sand and gravel bottom. In some locations of the channel there are scoured clay seams. In other locations the channel is composed of large cobbles up to 30 cm across.

Below 2800 m several small tributaries enter the main stream (Fig. 2).

Other features of the watershed are described in papers in the proceedings of the Carnation Creek Workshop, A Ten-Year Review (Hartman 1982).

METHODS

Intra-gravel and stream temperatures were measured with either a calibrating mercury thermometer or a thermistor probe and meter. The latter was calibrated to the mercury thermometer. To make measurements a 2.5 cm diameter pipe, 90 cm long, fitted around a pointed steel driving rod as its core, was used. The 8 to 10 cm section of the bottom end of the plastic pipe was perforated with about 20 four mm holes to allow entry of intra-gravel water after the pipe was driven and the driving core was pulled out.

When the pipe was driven to the depth desired (30 cm at all sites in the area above tidal influence) the probe or thermometer was lowered and the measurement was taken. If measurements were taken at several depths at one site, the driving rod was slowly re-inserted after each measurement and the pipe was driven to the next depth desired.

Although measurements were taken repeatedly during a one year period at some sites, a pipe was driven each time for a measurement. If pipes were left in the stream bottom the water temperature in them tended to equilibrate with that of the stream.

In all cases, the stream temperature was measured at the same site as the intra-gravel temperature with the same instrument. Stream temperatures were usually recorded at a depth of about 10 cm.

Some measurement sites were selected at the lower end of riffles, at sites considered to be potential coho spawning locations. Some were selected along the stream margin in both riffle and slow moving water. Aside from the choice of some sites considered to be potential coho spawning locations no particular effort was made to select specific kinds of measurement site within the stream zones studied.

Figure 2 shows the locations of the sections where measurements were made. In some cases, several measurements were made within a 50 m stretch of creek in order to determine how variable intra-gravel temperatures, taken at 30 cm depth, might be. Figure 2 indicates the 25 m section of stream in which measurements were made.

RESULTS

Scope of results

The measurements, upon which the figures in the results are based, are included in Appendices I, II, and III. Appendix I contains intra-gravel temperatures at 30 cm depth in the stream bottom and stream temperatures at the same location, but measured about 10 cm below the stream surface.

Appendix II contains data from those series of measurements in which intra-gravel temperatures were recorded at several depths in one location. Data given for intra-gravel temperatures at 30 cm depth in Appendix II were also given in Appendix I.

Appendix III contains intra-gravel and stream temperature measurements made within and immediately upstream of the part of the creek that is influenced by tides. In this part of the creek measurements were made at several depths in the gravel at most sites.

Although all measurements were not replicated in each series throughout the one year course of the study several definite aspects of the intra-gravel and stream temperature conditions emerge. These involve the following:

- relationship between the stream temperatures at about 10 cm depth and the intra-gravel temperatures at 30 cm depth.
- seasonal changes in the relationship between stream temperature and intra-gravel temperature.
- differences in stream temperature along the stream.
- variability in intra-gravel water temperature profiles with site,
- differences between intra-gravel water temperature profiles of the stream and those of the middle inter-tidal zone.

Relationship between stream temperature and intra-gravel temperature at 30 cm depth

There is a strong positive relationship between stream temperature and inter-gravel temperature (RXY=.9555) in the stream zone above 600 m (Fig. 3). The intra-gravel temperatures are high, relative to the stream temperature in the lower end of the curve and low relative the stream in the higher temperature conditions. The stream to intra-gravel temperature relationships for five 2 or 3 month periods indicated (Fig. 3).

Intra-gravel temperatures rose above those of the stream after early Nov., and fell below them after about April 1 (Fig. 4). At some sites intra-gravel temperatures differed from the stream temperatures by as much as 5.9°C in the winter and 3.7°C in the summer (see 1750 and 1775 m sections, Appendix I). The differences between stream and intra-gravel temperatures were lower when measurements were made early in the day. However only the degree of difference between intra-gravel and stream temperatures, during the different seasons, would have been different if all mesurements had been made in the morning. The pattern of the relationship between them would have been the same.

Temperature gradients along the stream

It is evident from data in Appendix I that intra-gravel temperatures are much lower in summer, and higher in winter, than those of the stream in some locations in particular (e.g. 775, 1750, 1800 m). (As examples of this, at 1750 m on Sept 6 the stream temperature was 16.0°C the gravel was 12.3°C, at 1775 m on Sept 12 the stream temperature was 15.0°C the gravel was 12.1°C. In the winter (Jan 1, 1982) at 1750 m the stream temperature was 3.16°C the gravel was 8.67°C. At 775 m on Feb 6 the stream temperature was 5.05°C the gravel was 8.62°C.) Stream temperatures along the stream are lower in summer downstream of the locations where the inter-gravel temperatures are low (Fig. 5). During the summer, below about 1800 m, the temperatures fall as the stream descends. This occurred in several series. (See temperature curves for June 18, July 18, Aug 11, Sept 6, and 7 curves, Fig. 5).

During winter and early spring, measurement series (see Nov 29, Feb 6, and April 25 lines, Fig. 5) stream temperatures are progressively higher downstream, over much of the zone studied.

The differences in temperature along the stream were not, in the cases cited, an artifact of the fact that the temperatures were recorded over a period of time during the day when the stream was warming or cooling as a result of diel changes.

Depth-temperature profiles in intra-gravel water

Intra-gravel water temperature profiles, measured in July and Aug 1982, were variable (Fig. 6). In some cases, intra-gravel temperatures were lower than those of the stream in other cases they were not (Fig. 6). The same variability, from one site to another, occurred in Nov. 1981 (Fig. 7). (Where there were measurements at the same locations, intra-gravel temperature

profiles from July 1, 1982 are re-plotted with Nov 29, 1981 data to facilitate comparison, Fig. 7.) Among the few sites for which July and Nov temperatures profiles are presented very distinct differences in seasonal temperature conditions are evident. At 719 m and 1762 m the intra-gravel temperatures (July and Nov) were the same or within one and one half degrees of each other (Fig. 7). The stream temperatures were 4.5 to 6°C different. At 769 m and 1679 m both the stream and gravel temperatures were separated by almost 6° in July-Nov comparisons. Most of the temperature change, with depth of intra-gravel water, occurs in the first 30 cm or less of gravel (Figs. 6 and 7).

Tidal influence

In Mar 1983 intra-gravel temperatures were higher than stream temperatures at corresponding sites in the zone of stream from 40 m above the 0 marker (see Fig. 2) to about -110 m (Fig. 8). The temperature profiles in this zone were similar to those observed in Nov in parts of the upstream area. From the -130 m point downstream the differences between the intra-gravel temperatures and corresponding site stream temperatures were relatively small. As was the case at the sites above tidal influence, where there were differences between the stream and intra-gravel temperatures, most of the temperature difference occurred in the top 10 cm of the stream substrate.

In June and Aug 1982 intra-gravel temperatures were generally lower than the stream temperatures from the +15 m site downstream to -60 m. Below the -70 m point intra-gravel temperatures were always somewhat higher than those of the stream (Fig. 9). As was the case in Mar 1983, (Fig. 8) the temperature gradient in the top 10 cm of stream bottom was very sharp. From the Mar period to the June-Aug period the relationships of intra-gravel temperatures to stream temperatures, in the upper and lower parts of the zone of tidal influence, are almost completely reversed (Figs. 8 and 9).

DISCUSSION

Variability in stream and intra-gravel temperatures above 600 m

The results of this work demonstrate that there are sites in Carnation Creek where the intra-gravel water is much cooler than the stream in summer and much warmer in winter. In the section of the stream from 1750 to 1800 m these conditions were most evident. At the 1750 m site intra-gravel temperatures at 30 cm depth ranged from 8.2°C to 13.1°C year round (Appendix I).

The stream temperatures immediately above, ranged from 3.13°C to 16.0°C year around. These values are similar to those recorded by Hansen (1975) in Poplar Creek, Michigan. The relationship between intra-gravel and

stream temperatures were similar to those at 1750 m at many other sites in Carnation Creek. However the degree of difference between intra-gravel tempeartures and stream temperatures was smaller than it was in the stream section from 1750 to 1800 m.

The conditions from 1750 to 1800 m suggest that there is a zone of ground water entry in this reach of stream. The weak upwelling of water, which occurred on some occasions when the measurement pipes were driven at the 1750 m in site, also suggested ground water entry to the stream. Hansen (1975) recorded "high potentiometric surfaces" that coincided with high groundwater temperatures.

Figure 5 indicates that in summer the stream temperature at the 1750 m site was much cooler than it was immediately upstream or downstream. This indicates that while there was intrusion of colder water into the stream there was also mixing downstream

Variability in stream and intra-gravel temperatures in the zone of tidal influence

In the uppermost part of the zone of tidal influence intra-gravel temperatures were cooler than the stream in summer and warmer in winter (Figs. 8 and 9). These conditions were similar to those observed further upstream. However, from about 50 to 100 m below the uppermost point of tidal influence the intra-gravel temperatures were generally warmer than the stream in summer and similar to them in winter (Figs. 8 and 9). The speculation offered in this paper is that in summer the incoming tide runs in over beach and gravel bank areas and warms as it does so. This warmed water penetrates into the drained substrate and subsequently percolates into the stream. Sheridan (1961) found evidence that salt water in inter-tidal areas warmed intra-gravel water to a depth of about 30 cm. In Jan and Mar the intra-gravel temperatures were similar to those of the stream from -70 and -130 m (see Fig. 2) downstream (Figs. 8 and 9).

It is evident that the processes that affect gravel and above bottom water temperature conditions may be different in the upstream zone than they are in the zone of tidal influence.

Intra-gravel temperature variability along the stream and invertebrate production

Migrations and occurrence of benthos in the substrate of a streambed have been reported by several authors (Williams 1981). Williams and Hynes (1974) demonstrated the occurrence of benthos deep in the substrate of a southern Ontario stream. They found maximum total numbers of organisms at 10 cm depth. However species from the orders Ephemeroptera, Trichoptera, Plecoptera, and Diptera occurred from 20 to 30 cm into the bottom. Species of Cyclops occurred at 60 cm depth and olegocheates were found at 70 cm down in the substrate.

At the locations where intra-gravel temperatures differed most widely from those of the stream a large part of the temperature gradient occurred in the top 20 cm of the stream bottom (Figs. 6 to 9). Invertebrates in the substrate in areas of groundwater influence would experience different conditions than those in direct contact with stream water or in locations where the stream temperatures influence the intra-gravel temperatures. In studies of invertebrate behavior and faunal distribution intra-gravel temperatures may constitute an important environmental influence along with substrate composition, water velocity and detritus abundance.

Control of hatching and emergence time in salmonid egg introductions

At some locations, in a stream such as Carnation Creek, eggs would experience about 2.5°C higher temperatures during much of the winter period. For the period of Nov to Feb inclusive, this would amount to about 300 CTU more than other sites in the same stream. Salmonid eggs in a stream having such complex intra-gravel temperature features might develop at widely differing rates to produce emerging fry early or late depending on where they were introduced. Whether fish culturists would wish to seek out such warm intra-gravel water sites would depend on their needs and the biology of the fish they work with. There are both advantages and disadvantages to early emergence of coho fry in Carnation Creek, (Hartman et al. 1982 and Scrivener and Anderson 1982). Fry which emerge early begin growing early and attain a relatively large size by fall (Hartman et al. in press). On the other hand fish which emerge early have a higher probability of experiencing freshets and moving seaward in such conditions (Scrivener and Andersen 1982). This paper recommends that Salmonid Enhancement workers, making artifical egg plants, assess intra-gravel temperature conditions (along with other conditions) and use the information to get locations that give the incubation regimes that are desired.

Fisheries-forestry considerations

A second consideration of these results applies to fisheries forestry planning. Exposure of a stream to increased sunlight leads to an elevation of stream temperatures (Brown 1980). If a stream is influenced along its length with ground water the warming effect, by sunlight (or warm air) may be offset to a degree as was presumed to have occurred in at and below about 1750 m in Carnation Creek. If managers are comparing stream temperatures in and above clear-cut areas they may not find elevated temperatures in the clear-cut areas if there is substantial ground water input.

In this work during several summer measurements series, the stream water became progressively cooler downstream in the clear cut area in the zone where the inter-gravel water was very cool. It may be feasible for management workers to examine ground water input (locations and temperatures) and plan clear-cuts in such a fashion as to take advantage of cool water input. At this stage limitations in knowledge of ground water temperature dynamics and factors governing the locations of ground water influence along a stream probably prevents planning.

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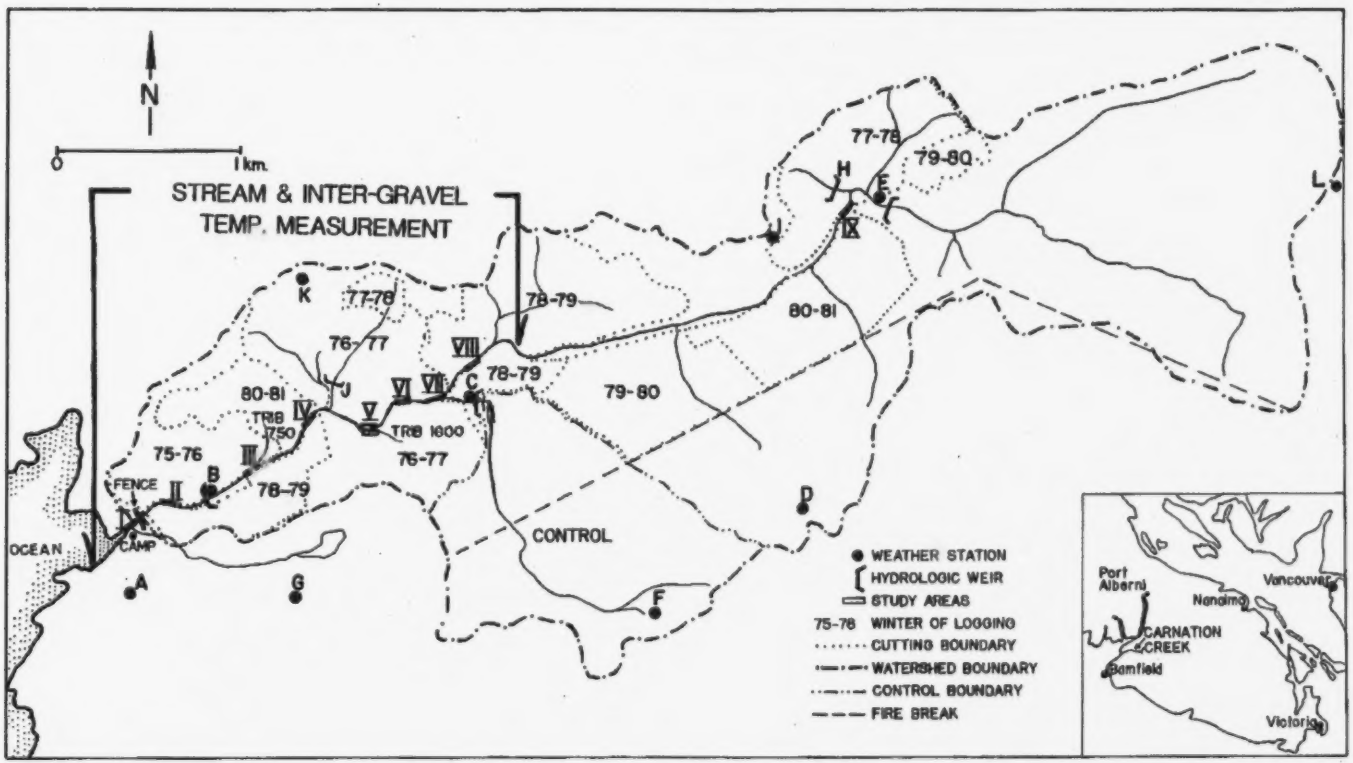

Fig. 1. The Carnation Creek drainage area. The zone in which stream and intra-gravel temperatures were measured is indicated between the two vertical arrows.

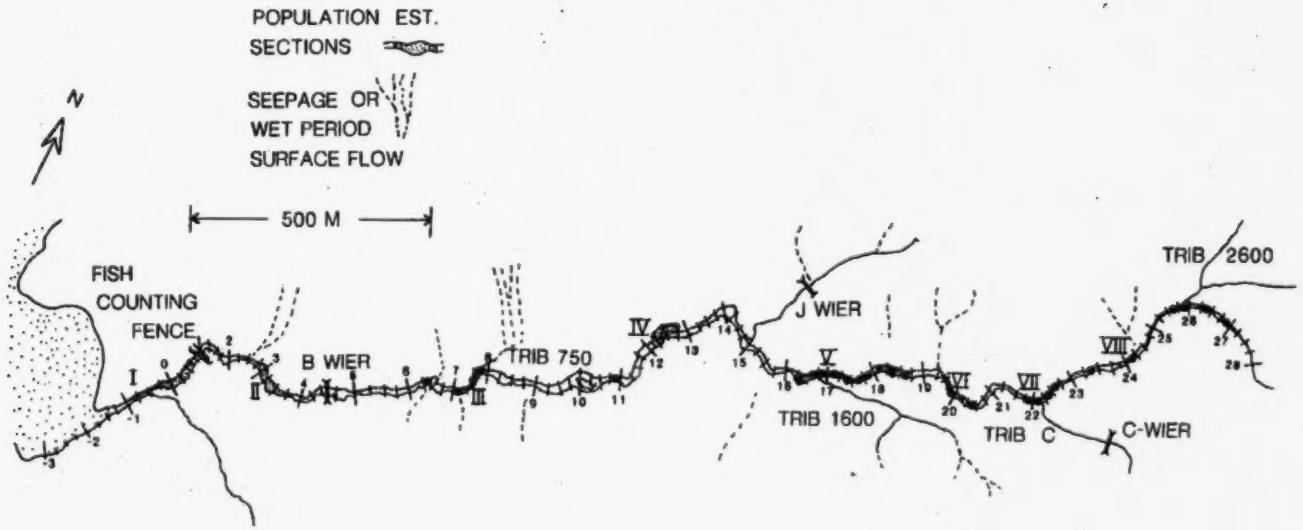

Fig. 2. The zone in which stream and intra-gravel temperatures were measured. The numbers -3 to 27 indicate the downstream ends of the 100 m sections in which measurements were made. Each 100 m section is divided into four 25 m sections. Heavy dots indicate the 25 m sections in which measurements were made. In some cases measurements were taken at more than one point within a 25 m section.

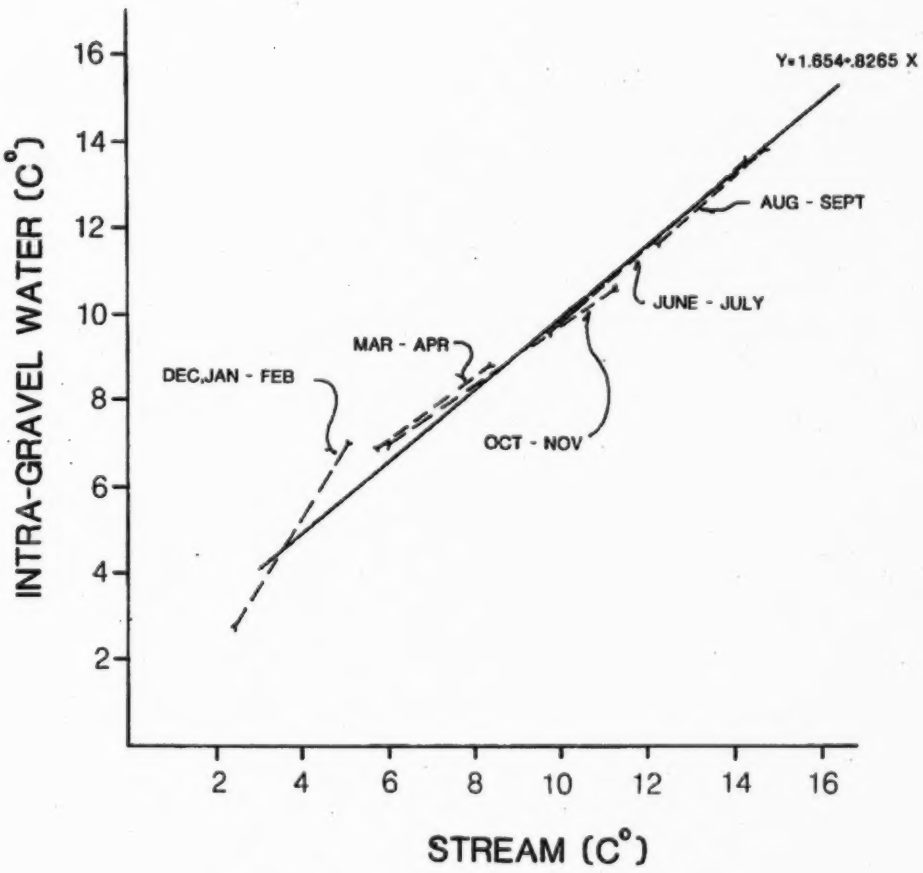

Fig. 3. Relationship between the stream and intra-gravel temperature. The unbroken line is based on all measurements, taken year round, above the zone of tidal influence. The approximate range of temperatures and relationships for the individual periods are indicated by the broken lines.

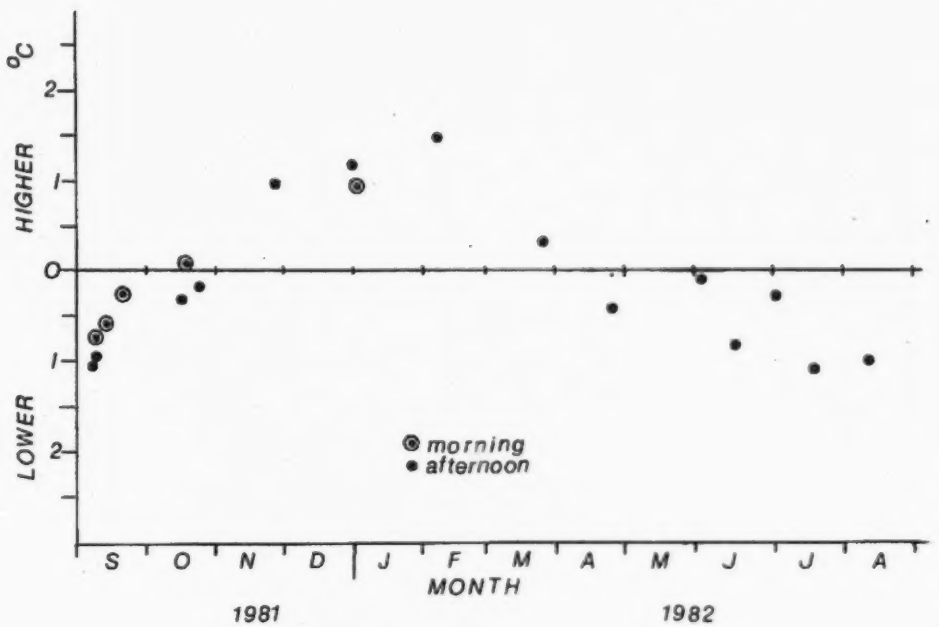

Fig. 4. The difference between mean intra-gravel temperature and mean stream temperature. A single point is based on the measurements taken in one series of measurements from in the stream zone at and above 625 m. Points located above the 0 line, i.e. "HIGHER" indicate that the intra-gravel temperatures were above those of the stream.

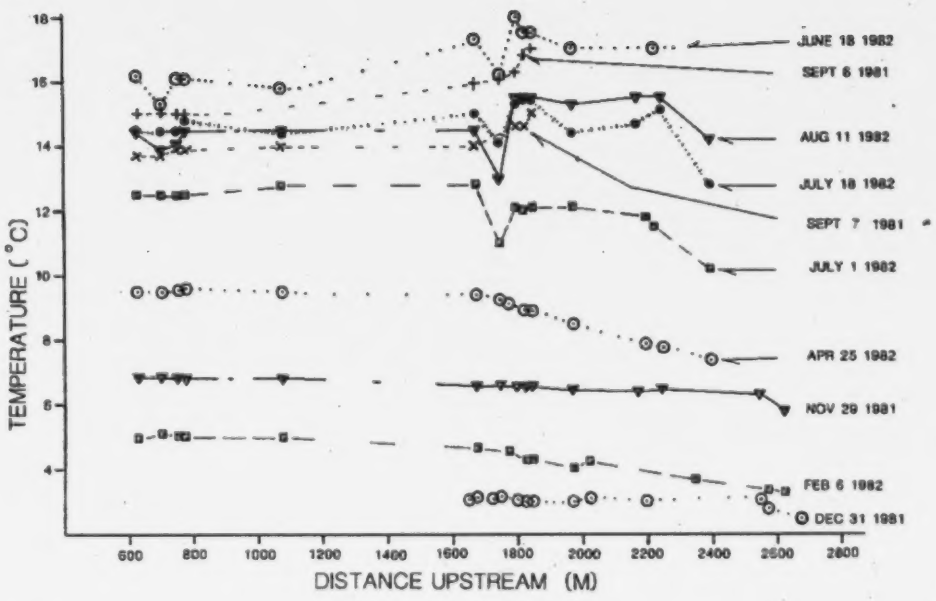

Fig. 5. Temperatures measured within the stream at locations corresponding to the intra-gravel temperatures measurements. The time periods during which measurements were made are indicated in Appendix I.

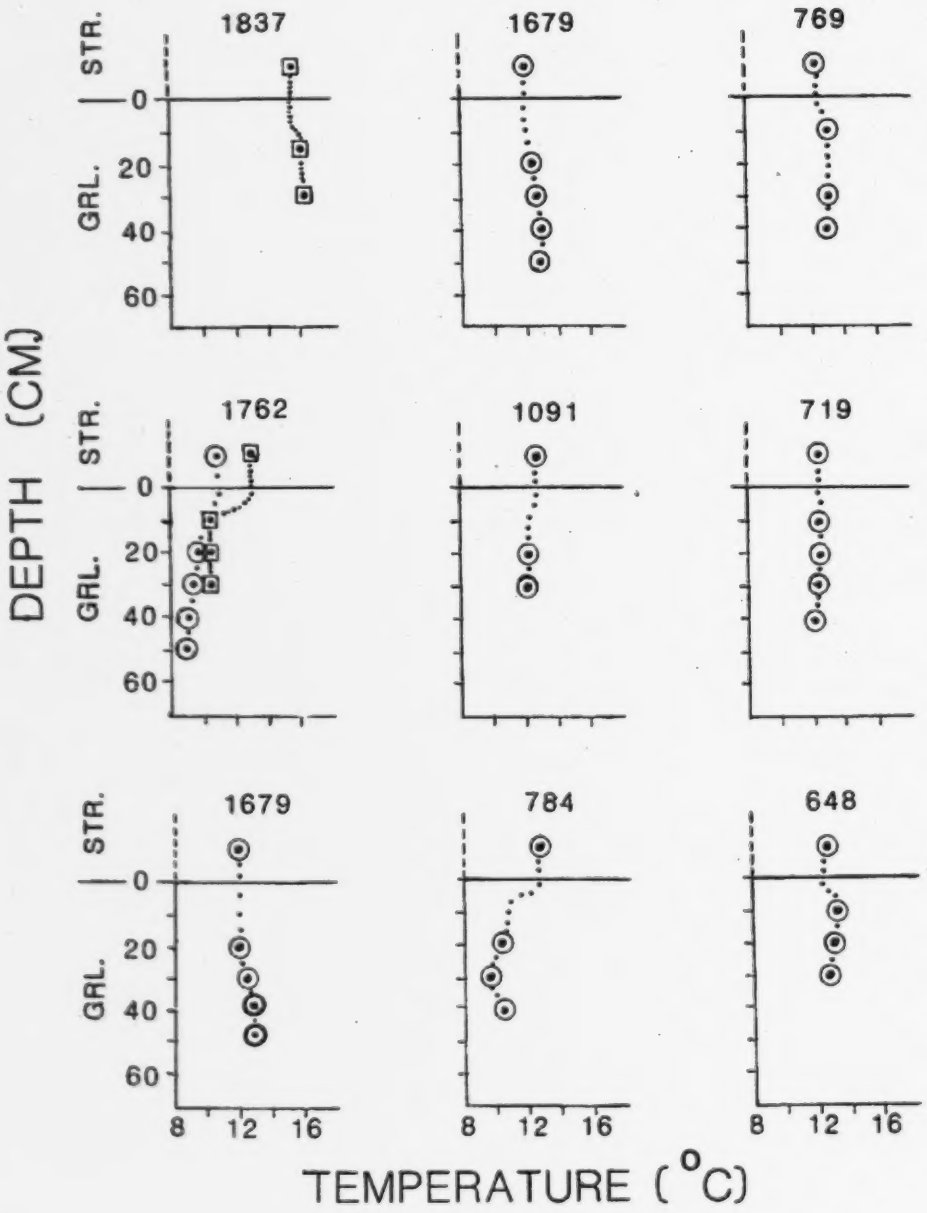

Fig. 6. Stream bottom temperature profiles at sites above 625 m July 1, 1982 (dots inside circles) and Aug. 11, 1982 (dots inside squares). The vertical axis below '0' line indicates the depths in the gravel (GRL) at which measurements were made. Measurements in the stream (STR) were usually taken about 10 cm below the stream surface.

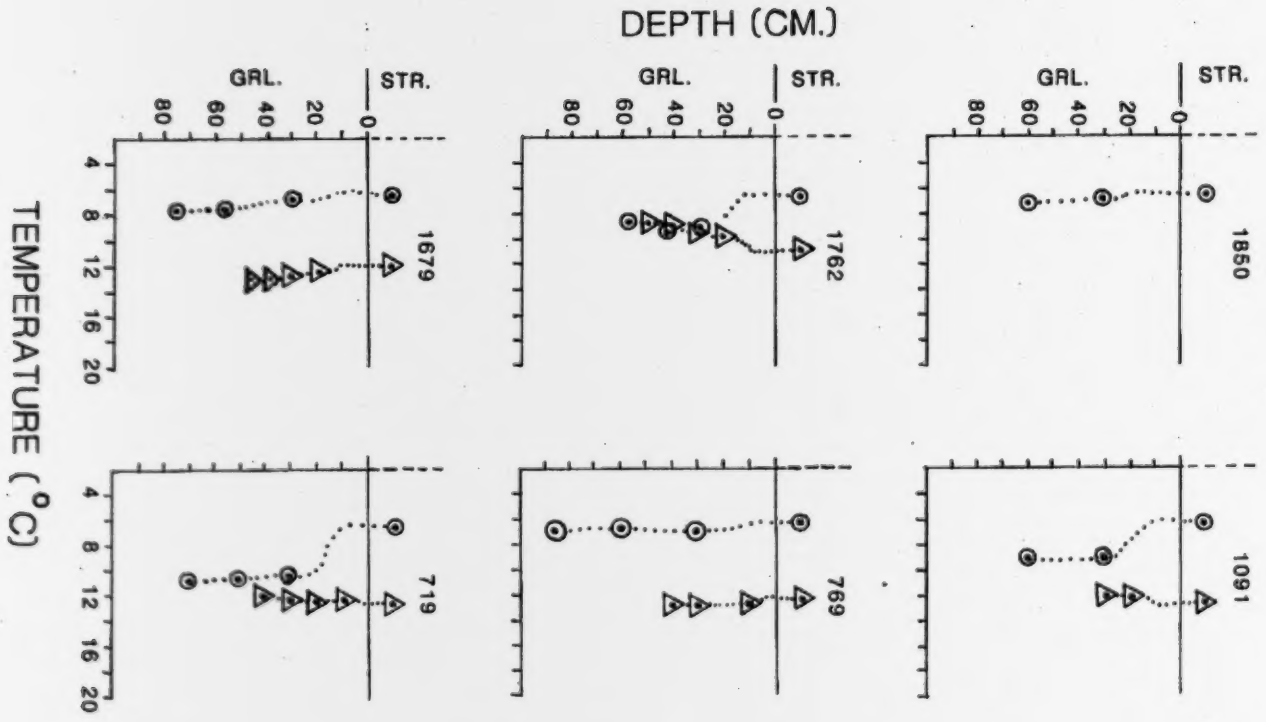

Fig. 7. Stream bottom temperature profiles Nov. 29, 1981 at sites above 625 m (dots in circles). Profiles for corresponding sites, based on part of the July 1 data (dots in triangles) are shown for comparison. The vertical axis below the '0' line indicates the depth in the gravel (GRL) at which the measurements were made. Measurements in the stream (STR) were usually taken about 10 cm below the stream surface.

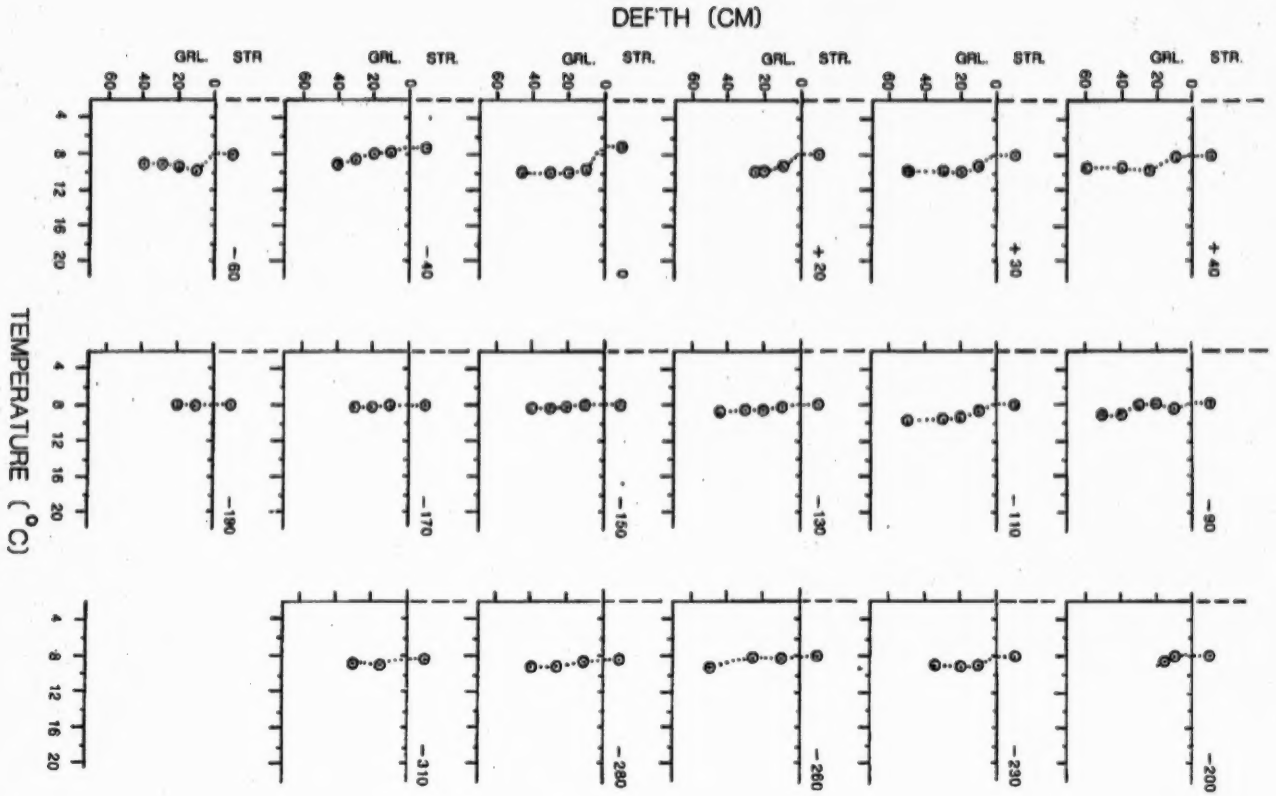

Fig. 8. Temperature profiles at sites within the zone of stream influenced by tides, on Mar. 18, 1983. The +40 indicates that the measurements were taken 40 m upstream from the 0 point (see Fig. 2). The -310 indicates measurements taken 310 m below the 0 point. The vertical axis below '0' line on each graph indicates the depths in the gravel (GRL) at which the intra-gravel water temperature measurements were made. Measurements in the stream (STR) were usually taken about 10 cm below the surface.

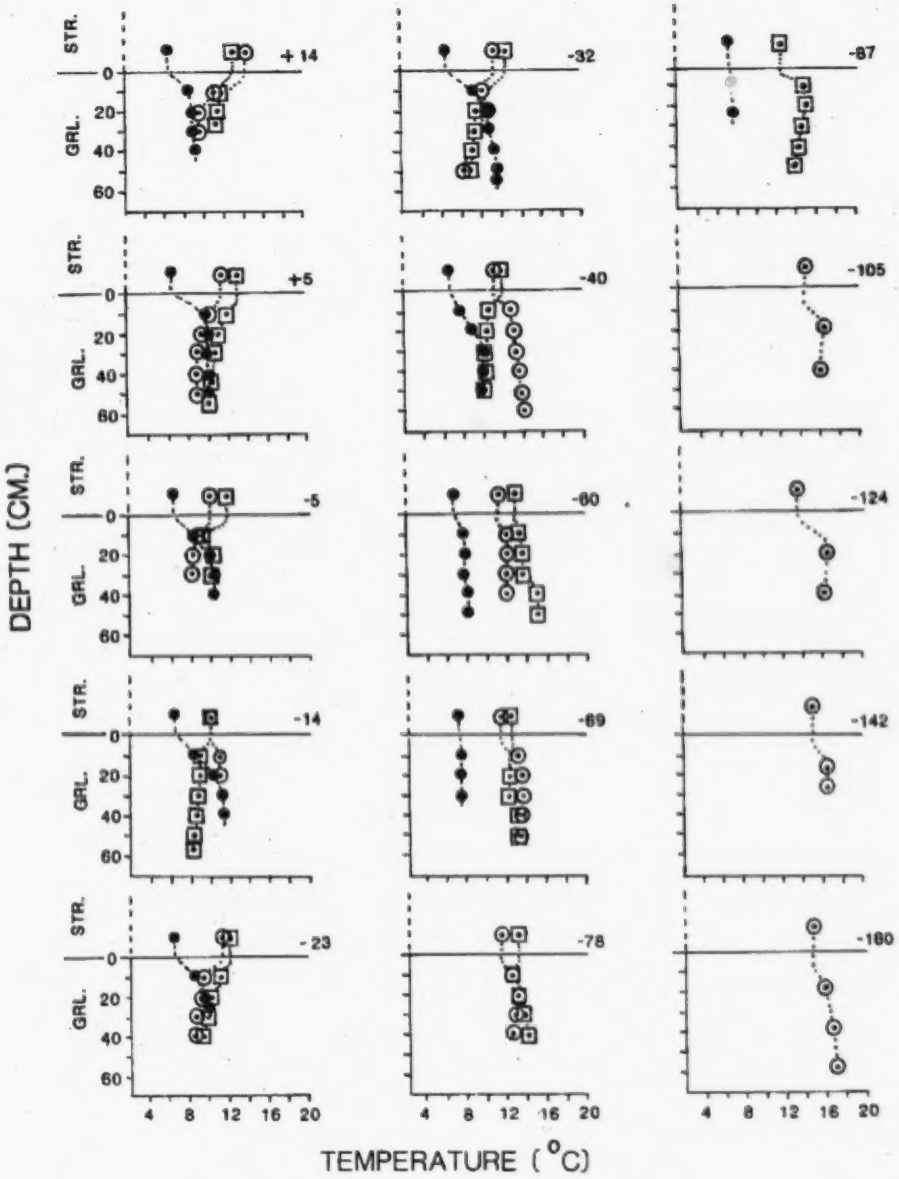

Fig. 9. Temperature profiles, at sites within the zone of stream influenced by tides, on Jan. 17, 1983 (solid dots joined by broken line), Jun 21, 1982 (small dots within circles joined by dotted line) and Aug. 12, 1982 (small dots within squares joined by dotted line). The +14 indicates that the measurements were made 14 m upstream from the 0 mark (see Fig. 2). The -160 indicates that measurements were made 160 m downstream from the 0 mark. The vertical axis below the '0' line on each graph indicates the depths in the gravel (GRL) at which the measurements were made. Measurements taken in the stream (STR) were usually taken about 10 cm below the surface.

Appendix I. Stream and intra-gravel water temperatures (S & G). Intra-gravel temperature are measured at 30 cm depth. The stream section colum indicates the lower end of the 25 m section in which the measurement was made. More than one pair of data points in a given section indicates several readings for the section, not necessarily all taken at the same site within the 25 m section.

Date & Time 1981		STREAM SECTION (SEE FIG. 2) 625	700	750	775	1075	1625	1650	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675	Mean	S.D.
Sept. 6,	S	15.0	15.0	15.0	15.0	-	-	-	15.9	-	-	16.0	-	16.3	16.8	17.0													15.79	.82
	G	14.5	13.2	14.6	13.4	-	-	-	15.5	-	-	12.3	-	16.1	16.1	17.5													14.78	1.65
13.15-																														
16.50	S								16.1																					
	G								15.1																					
Sept. 7,	S	13.7	13.7	14.0	13.9	14.0	-	-	14.0	-	-	14.0	-	14.6	14.6	15.0													14.15	.43
	G	13.7	12.8	14.0	12.1	13.1	-	-	14.1	-	-	11.3	-	12.0	13.8	14.3													13.12	1.03
09.05-																														
10.45	S								14.0																					
	G								14.0																					
Sept. 12,	S	14.1	14.2	14.4	14.4	14.9	15.1	15.2	15.0	15.0	15.5	15.2	15.0	15.9	15.8	16.0													15.06	.58
	G	14.0	14.1	14.4	12.2	13.6	13.0	16.0	15.0	13.1	15.8	13.1	11.1	13.5	15.2	14.5													14.04	1.25
13.05-																														
16.50	S								15.1		15.3		15.8	16.0	15.5	16.0														
	G								14.3		14.3		12.3	16.2	15.2	16.1														
	S								15.2							15.9														
	G								15.0							16.1														
Sept. 13,	S	12.9	12.9	12.9	12.9	13.0	-	-	12.2	-	-	12.2	-	12.9	13.2	13.0													12.81	.33
	G	12.9	12.0	12.9	11.7	12.1	-	-	12.7	-	-	10.7	-	11.1	12.8	12.9													12.18	.80

Appendix I. (cont'd)

Date & Time 1981		STREAM SECTION (SEE FIG. 2) 625	700	750	775	1075	1625	1690	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675	Mean	S.D.
07.25-09.00	S								12.2																				
	G								12.7																				
Sept. 20,	S	12.9	12.9	12.9	12.9	12.9	-	-	12.7	-	-	12.9	-	13.0	13.0	13.0												12.91	.01
	G	13.0	12.5	12.9	12.5	13.0	-	-	13.2	-	-	11.5	-	11.8	13.0	13.0												12.63	.56
10.20-11.40	S								12.7																				
	G								13.0																				
Oct. 17,	S	10.8	10.8	10.7	10.7	11.3	-	-	11.5	-	-	11.6	-	11.6	11.5	11.6												11.21	.41
	G	10.2	11.2	10.7	10.3	10.3	-	-	12.1	-	-	10.2	-	11.0	11.0	11.8												10.82	.57
14.20-16.12	S								11.6																				
	G								10.9																				
Oct. 18,	S	9.7	9.7	9.8	9.8	10.8	-	-	10.0	-	-	10.0	-	10.1	10.1	10.1												10.01	.32
	G	10.0	10.8	10.1	10.1	9.8	-	-	10.3	-	-	9.6	-	9.8	10.0	10.3												10.05	.33
11.10-12.31	S								10.0																				
	G								9.7																				
Oct. 24,	S	9.7	9.8	9.8	9.8	9.9	-	-	10.1	-	-	10.2	-	10.2	10.2	10.2												9.99	.20
	G	9.6	10.8	9.4	10.1	9.4	-	-	9.4	-	-	9.3	-	9.8	9.9	10.0												9.79	.45

Appendix 1. (cont'd)

Date & Time 1981		STREAM SECTION (SEE FIG. 2) 625	700	750	775	1075	1625	1650	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675	Mean	S.D.
14.45-16.45	S								10.1																					
	G								9.8																					
Nov. 27, 12.55-13.36	S	-	-	-	7.2	7.5	-	-	7.5	-	-	-	-	-	7.5	7.5	-	-	-	-	-	-	-	-	-	-	-	-	7.44	.13
	G	-	-	-	7.5	7.5	-	-	7.5	-	-	-	-	-	7.5	7.5	-	-	-	-	-	-	-	-	-	-	-	-	7.50	.00
Nov. 29, 10.00-15.40	S	6.85	6.88	6.85	6.85	6.82	-	-	6.62	-	-	6.62	-	6.57	6.54	6.57	6.51	-	6.42	-	-	6.48	-	-	6.31	-	5.79	-	6.59	.29
	G	7.22	10.26	7.00	10.07	7.79	-	-	6.80	-	-	9.05	-	7.31	6.77	6.74	6.77	-	6.74	-	-	6.91	-	-	7.25	-	5.65	-	7.55	1.35
	S					6.82			6.62																					
	G					9.26			6.51																					
	S					6.82																								
	G					9.23																								
Dec. 31, 14.55-16.10-	S	-	-	-	-	-	-	3.06	3.11	-	3.08	3.16	-	3.03	2.98	2.98	2.98	3.06	-	2.96	-	-	-	-	-	-	-	2.43	3.08	
	G	-	-	-	-	-	-	2.96	4.21	-	3.67	8.67	-	3.18	3.31	2.98	3.78	3.99	-	3.31	-	-	-	-	-	-	-	4.18	3.96	
	S							3.08	3.08			3.13					3.03			3.01										
	G							3.06	3.16			3.31					5.36			4.26										
	S							3.06				3.13																		
	G							2.96				9.05																		

Appendix 1. (cont'd)

Date & Time 1982		STREAM SECTION (SEE FIG. 2)																											Mean	S.D.
		625	700	750	775	1075	1625	1650	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675		
Jan. 1, 82 11.07-11.36	S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.01	2.76	-	-	2.93	-
	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.94	2.74	-	-	2.25	-
	S																													
	G																								3.03 3.08					
Feb. 6, 10.00-14.45	S	4.99	5.10	5.05	5.05	4.99	-	-	4.65	-	-	-	4.57	-	4.24	4.24	4.02	4.21	-	-	-	-	3.67	-	-	3.36	3.23	-	4.40	.63
	G	5.33	7.05	4.71	8.62	7.17	-	-	5.36	-	-	-	9.15	-	4.10	5.08	4.74	4.29	-	-	-	-	3.75	-	-	3.94	4.65	-	5.79	1.88
	S								4.65				4.68					4.16												
	G								4.89				8.91					4.49												
	S													4.40																
	G													9.02																
Mar. 28, 15.30-17.55	S	7.0	7.0	7.0	7.0	6.8	-	-	6.5	-	-	6.3	-	6.3	6.3	6.3	6.0	6.0	6.0	-	-	6.0	5.8	-	-	-	-	-	6.42	.43
	G	6.3	6.6	6.6	7.2	7.2	-	-	6.3	-	-	8.2	-	8.3	6.5	6.5	6.2	6.3	6.1	-	-	6.0	6.4	-	-	-	-	-	6.72	.70
	S								6.5								6.0													
	G								6.3								6.5													

Appendix I. (cont'd)

Date & Time 1982		STREAM SECTION (SEE FIG. 2)																											Mean	S.D.
		625	700	750	775	1075	1625	1660	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675		
Apr. 25, 15.00-17.20	S	9.5	9.5	9.58	9.63	9.52	-	-	9.39	-	-	9.23	9.13	-	8.94	8.91	8.51	-	-	7.90	-	7.76	-	7.37	-	-	-	-	8.91	.74
	G	8.67	7.96	8.34	8.40	8.86	-	-	7.98	-	-	9.55	8.81	-	8.99	9.29	7.96	-	-	8.21	-	8.45	-	7.11	-	-	-	-	8.49	.65
June 2, 14.50-16.30	S	10.5	10.6	10.6	11.0	-	-	-	10.5	-	-	10.1	-	10.5	10.5	10.4	10.3	-	-	10.9	10.8	-	-	10.0	-	-	-	-	10.51	.28
	G	11.0	11.1	11.1	9.2	-	-	-	11.3	-	-	9.6	-	10.0	10.5	10.9	10.3	-	-	10.2	10.5	-	-	10.2	-	-	-	-	10.44	.61
	S								10.5																					
	G								11.0																					
June 18, 17.05-18.09	S	16.2	15.3	16.1	16.1	15.8	-	-	17.3	-	-	16.2	-	18.0	17.5	17.5	17.0	-	-	17.0	17.0	-	-	18.0	-	-	-	-	16.79	.84
	G	16.2	14.3	16.2	16.2	14.2	-	-	15.5	-	-	12.5	-	18.8	18.0	15.2	15.8	-	-	17.8	17.5	-	-	14.9	-	-	-	-	15.97	1.70
	S								17.3																					
	G								16.5																					
July 1, 13.46-16.03	S	12.5	12.5	12.5	12.5	12.8	-	-	12.0	-	-	11.0	-	12.1	12.1	12.1	12.1	-	-	11.8	11.5	-	-	10.2	-	-	-	-	12.00	.70
	G	12.8	12.3	13.0	9.5	12.2	-	-	12.5	-	-	9.5	-	11.5	12.2	11.5	12.1	-	-	12.0	12.1	-	-	11.1	-	-	-	-	11.73	1.06

Appendix I. (cont'd)

Date & Time 1982		STREAM SECTION (SEE FIG. 2)																											Mean	S.D.
		625	700	750	775	1075	1625	1650	1675	1700	1725	1750	1775	1800	1825	1850	1975	2025	2175	2200	2225	2250	2350	2400	2550	2575	2625	2675		
	S								12.0																					
	G								12.5																					
July 18, 13.00-14.57	S	14.5	14.5	14.5	14.8	14.5	-	-	15.0	-	-	14.1	-	15.3	15.5	15.5	14.4	-	14.7	-	-	15.7	-	12.8	-	-	-	-	14.66	.68
	G	14.1	12.9	13.8	10.6	13.2	-	-	14.5	-	-	10.3	-	14.5	15.0	14.9	14.5	-	14.7	-	-	15.3	-	12.0	-	-	-	-	13.59	1.61
	S								15.0																					
	G								14.5																					
Aug 11, 14.45-16.27	S	14.3	13.9	14.1	14.5	14.5	-	-	14.5	-	-	13.0	-	15.5	15.5	15.5	15.3	-	15.5	-	-	15.5	-	14.2	-	-	-	-	14.70	.78
	G	13.4	13.0	13.5	11.0	13.0	-	-	14.5	-	-	10.5	-	12.5	16.2	14.0	15.0	-	16.0	-	-	16.5	-	13.0	-	-	-	-	13.70	1.80
	S								14.5																					
	G								14.0																					

Appendix II. Stream and intra-gravel temperatures. This appendix provides data from those temperature series in which readings were taken at several depths in the gravel at the sites indicated.

Date & Time	Measure Location Stream, or gravel depth	625	700	750	775	1075	1675	1675	1750	1800	1825	1860	1975	2175	2200	2225	2250	2400	2550	2575	2625
1981																					
Nov 29, 10.00-	stream	6.85	6.88	6.85	6.85	6.82	6.62	-	6.62	6.57	6.54	6.57	6.51	6.42	-	-	6.48		6.31		5.79
15.40	30	7.22	10.26	7.00	10.07	9.26	6.80	-	9.05	7.31	6.77	6.74	6.77	6.74	-	-	6.91		7.25		5.65
	40	-	-	-	-	-	-	-	9.15	-	-	-	-	-	-	-	-		-		-
	50	-	10.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-		-
	55	-	-	-	-	-	7.42	-	8.72	-	-	-	-	-	-	-	-		-		-
	60	-	-	6.91	-	9.53	-	-	-	-	-	7.22	-	-	-	-	-		-		-
	70	-	10.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-		-
	75	-	-	-	-	-	7.59	-	-	-	-	-	-	-	-	-	-		-		-
	85	-	-	7.02	-	-	-	-	-	-	-	-	-	-	-	-	-		-		-
1982	stream	12.5	12.5	12.5	12.5	12.8	12.0	12.0	11.0	12.1	12.1	12.1	12.1	-	11.8	11.5	-	10.2	-		-
July 1, 13.46-	10	13.0	12.5	13.0	-	-	-	12.0	-	-	-	-	-	-	-	-	-	-	-		-
16.03	20	13.0	12.5	-	10.1	12.2	12.2	12.5	9.8	-	-	-	-	-	-	-	-	-	-		-
	30	12.8	12.3	13.0	9.5	12.2	12.5	-	9.5	11.5	12.2	11.5	12.1	-	12.0	12.0	-	11.1	-		-
	40	-	12.0	13.0	10.5	-	13.0	-	9.0	-	-	-	-	-	-	-	-	-	-		-
	50	-	-	-	-	-	13.0	-	9.0	-	-	-	-	-	-	-	-	-	-		-
Aug 11, 14.45-	stream	14.3	13.9	14.1	14.5	14.5	14.5	14.5	13.0	15.5	15.5	15.5	15.3	15.5	-	-	15.5	14.2	-		-
16.27	10	-	-	-	-	-	-	-	10.5	-	-	-	-	-	-	-	-	-	-		-
	15	-	-	-	-	-	-	-	-	-	16.0	-	-	-	-	-	-	-	-		-
	20	-	-	-	-	-	-	-	10.5	-	-	-	-	-	-	-	-	-	-		-
	30	13.4	13.0	13.5	11.0	13.0	14.5	14.0	10.5	12.5	16.2	14.0	15.0	16.5	-	-	16.0	13.0	-		-

Appendix III. Stream and intra-gravel water temperatures taken in the lower portion of Carnation Creek which is under tidal influence. Gravel depth column indicates the depth in the stream bed at which measurements were made.

Date & Time	Measure Location Stream or gravel depth	+40	+30	+20	+14	+6	0	-6	-14	-23	-32	-40	-60	-69	-73	-78	-87	-93	-105	-110	-124	-130	-142	-150	-160	-170	-190	-200	-230	-260	-280	-310	Boat
21 June, '82	stream	-	-	-	14.2	11.5	-	10.0	10.0	11.5	11.2	11.0	11.5	11.5	-	11.8	-	-	14.3	-	13.6	-	15.0	-	15.0	13.8	-	-	-	-	-	-	-
09.50-																																	
12.06	10				11.1	10.2	-	8.8	11.0	9.3	10.1	12.9	12.0	13.1	-	12.3	-	-	-	-	-	-	-	-	-	17.0	-	-	-	-	-	-	-
	20	-	-	-	9.5	9.5	-	8.2	11.0	9.1	10.5	13.0	12.1	13.3	-	13.1	-	-	16.6	-	16.8	-	16.4	-	16.0	-	-	-	-	-	-	-	-
	30	-	-	-	9.5	9.3	-	8.2	-	8.5	9.5	13.3	12.1	13.5	-	13.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	9.2	-	-	-	8.5	9.1	13.5	12.0	13.2	-	12.5	-	-	16.1	-	16.2	-	16.5	-	17.0	-	-	-	-	-	-	-	-
	50	-	-	-	-	9.5	-	-	-	-	8.6	-	-	13.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	60	-	-	-	-	-	-	-	-	-	-	14.1	-	-	-	-	-	-	-	-	-	-	-	-	17.2	-	-	-	-	-	-	-	15.8
12 Aug, '82	stream				13.1	13.2	-	11.8	10.0	12.0	12.5	11.8	12.5	12.3	-	13.0	12.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.1
	10	-	-	-	11.8	12.0	-	9.0	9.0	11.1	10.2	10.8	13.2	-	-	12.3	14.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.2
10.15-	20	-	-	-	11.5	11.0	-	10.1	9.0	10.4	9.4	10.5	13.8	12.2	-	13.0	15.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13.00	25	-	-	-	11.2	-	-	10.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.0
	30	-	-	-	-	10.8	-	-	8.8	9.9	9.4	10.2	13.8	12.2	-	13.5	14.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	-	-	-	-	8.8	9.5	-	10.2	15.0	13.1	-	13.9	14.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	46	-	-	-	-	10.3	-	-	8.5	-	-	-	15.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	50	-	-	-	-	-	-	-	-	-	9.0	10.2	-	13.0	-	-	14.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	55	-	-	-	-	10.0	-	-	10.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17 Jan, '83	stream	-	-	-	8.2	8.2	-	8.2	8.2	8.5	8.5	8.4	8.9	-	7.0	-	8.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	8.25	10.0	-	8.5	8.2	8.5	9.2	7.5	7.5	-	7.2	-	7.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
09.51	20	-	-	-	8.8	10.0	-	10.0	10.2	9.4	10.8	8.7	7.8	-	7.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12.27	25	-	-	-	-	-	-	-	-	10.0	-	-	-	-	-	-	7.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	30	-	-	-	8.8	10.0	-	10.5	11.0	-	10.8	10.0	7.5	-	7.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	40	-	-	-	9.0	10.5	-	10.2	11.2	-	11.2	10.0	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	50	-	-	-	-	10.0	-	-	-	-	11.5	9.8	8.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	55	-	-	-	-	-	-	-	-	-	11.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1 Mar, '83	stream	8.0	8.0	8.0	-	-	7.0	-	-	-	-	7.2	8.0	-	-	-	-	7.8	-	8.0	-	8.0	-	7.9	-	8.0	8.0	8.0	8.0	8.0	8.2	8.2	-
	10	8.2	9.2	9.2	-	-	9.5	-	-	-	-	7.7	9.8	-	-	-	-	8.5	-	8.7	-	8.5	-	8.0	-	8.0	8.0	8.1	8.9	8.1	8.5	-	-
09.53	15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.6	-	-	-	-	8.8	-
-11.50	20	-	10.0	9.6	-	-	10.0	-	-	-	-	7.8	9.5	-	-	-	-	8.0	-	9.4	-	8.5	-	8.2	-	8.2	8.0	-	8.9	-	-	-	-
	25	9.8	-	9.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.3	-	8.2	-	-	-	8.1	9.0	8.5	-
	30	-	9.8	-	-	-	10.0	-	-	-	-	8.5	9.1	-	-	-	-	8.0	-	9.6	-	8.5	-	-	-	-	-	-	9.0	-	-	-	-
	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.3	-	-	-	-	-	-	9.0	-	-
	40	9.5	-	-	-	-	-	-	-	-	-	9.1	9.1	-	-	-	-	9.0	-	-	-	8.8	-	-	-	-	-	-	-	9.0	-	-	-
	45	-	-	-	-	-	10.0	-	-	-	-	-	-	-	-	-	-	-	-	9.7	-	-	-	-	-	-	-	-	-	-	-	-	-
	50	-	9.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	60	9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

12.00 - 12.14 hr